

Forging New Partnerships through the Use of Environmental Test Facilities

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Abstract

Increasing demands from researchers and the science community are driving environmental test facilities to be more versatile with increased capabilities. At the same time, maintaining a cost-effective approach to test operations has driven efforts to use these facilities for purposes beyond their original design. This paper presents an overview of the Jet Propulsion Laboratory's efforts to provide JPL's space flight projects with test facilities to meet unique test requirements and to serve the needs of selected outside customers. The large number of recent Mars Missions, including the Mars Pathfinder project, have required testing of components and systems in a Martian surface environment in facilities originally designed for deep space testing. The unique problems associated with performing these tests are discussed, along with practical solutions. Other unique test requirements are discussed including the use of space simulation chambers for testing high altitude balloon gondolas and the use of vacuum chambers for system level test firing of an ion propulsion engine.

Key Words

Environmental Test, Space Simulation, Mars Environment

Introduction

Aerospace environmental testing has seen many innovations from the early days of aircraft testing to the early years of the "space race" to the present day of "faster, better, cheaper". During all of these phases of testing aerospace hardware for flight operations, there has always been a need for engineers in the test community to work with the scientists and researchers to provide test facilities and test methodologies that would meet all the requirements for a successful test program. In today's ever-changing world of spacecraft testing, it has become even more important

for the test and evaluation community to form close relationships with the science and research communities to ensure successful test results that meet the project's requirements. Many unusual and unique test requirements have been levied on environmental test labs in recent years due to the renewed interest in the exploration of the Martian surface. These requirements along with the thrust for "faster, better, cheaper" projects have led to new and innovative test techniques.

Brief History of Aerospace Environmental Testing

Environmental testing of components and systems has taken place since the early days of aircraft design and production but really came of age during the early years of the jet aircraft. When the Russians put Sputnik in orbit in 1956, the aircraft industry had in place advanced methods of vibration, shock, aerodynamic and thermal testing; however, testing of hardware that would be exposed to space opened a new era in environmental testing. The dynamics test field needed only minor adjustments to transition from aircraft testing to launch vehicle testing but the deep space environment was much more than just high altitude testing and a new field of simulating the space environment was born. New fields of testing included the use of cryogenic fluids to simulate the cold of outer space, higher levels of vacuum, and the great-unknown solar radiation effects in space. In recent years the increased use of optical components in space flight instruments has levied a whole new set of cleanliness requirements on environmental test laboratories. Working closely with the scientists, new methods of contamination control and ultra clean vacuum systems have been implemented in aerospace test laboratories. In addition "faster, better, cheaper" has given rise to many new challenges to both the science community and the test community.

The JPL Environmental Test Facilities

The Jet Propulsion Laboratory (JPL), an operating division of the California Institute of Technology (Caltech), is a lead research center for the National Aeronautics and Space Administration (NASA). JPL has a wide-ranging charter for Solar System exploration, earth observation, and technology development.

As part of this charter, JPL maintains NASA owned environmental test facilities for its research and development programs. These facilities include thermal vacuum test chambers, vibration tables, an acoustic chamber, and two large space simulation chambers. The Environmental Test Laboratory (ETL) at JPL has numerous horizontal thermal

vacuum chambers ranging in size from 3 ft by 3 ft to 11 ft by 11 ft. These chambers are capable of providing an outer space environment of better than 1×10^{-6} Torr at -185°C . The thermal vacuum lab also has several vacuum bakeout chambers, capable of attaining high vacuum at temperatures of over 100°C . The ETL has vibration and acoustic test systems for simulating space flight launch environments. The vibration systems range in size from 5,000 to 40,000 pounds of force. The acoustic test facility is a 10,900 cubic foot chamber capable of noise levels up to 155 dB. The ETL operates and maintains both 25-ft and 10-ft Space Simulator Facilities. These two large vertical thermal vacuum chambers are capable of providing an outer space environment of better than 1×10^{-6} Torr at -185°C . The 25-ft Space Simulator (See Figure 1) is 85 ft in

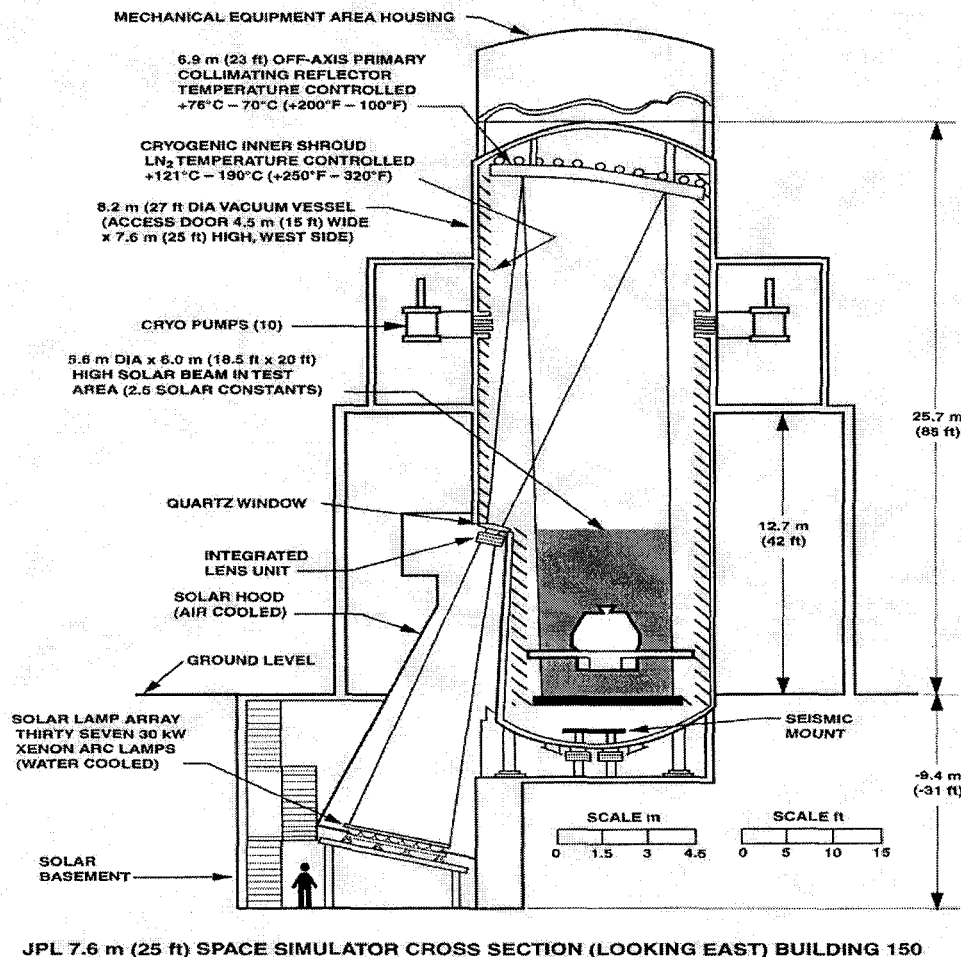


Figure 1: The JPL 25-ft Space Simulator Facility

height and has the added capability of producing a 19-ft diameter solar beam with radiation levels greater than 2.5 solar constants. Also included in this facility is the Satellite Test Assistant Robot (STAR) system, a remote controlled video imaging and infrared camera system, designed to aid test personnel in monitoring their test article in the chamber.

Unique Requirements from the Science and New Technology Community for Spacecraft Testing

Recent requirements to perform thermal vacuum tests in a simulated Martian surface environment have presented many new challenges to the environmental test community. Requirements such as operating a Mars lander and rover vehicle at 7 Torr and -100°C or performing thermal vacuum tests with a 20 meter/second wind in a CO_2 environment were some of the challenges during the Mars Pathfinder test program which led to the very successful landing on Mars in July, 1997. Another unique test requirement was the firing of an ion thruster engine during the space simulation test program for the Deep Space-1 (DS-1) flight spacecraft. Ion engines had successfully been tested in specially designed vacuum chambers in a stand-alone configuration, but never in a space simulation chamber as an integral part of a system level flight acceptance test. During the design and development of the Hubble Space Telescope, the scientists and researchers designing the optical imaging systems presented the test community with the challenge of providing ultra clean vacuum tests and vacuum bakeout testing. These more stringent tests were necessary to ensure spacecraft cleanliness to levels never previously attempted. All of these unique test requirements have necessitated a close working relationship between the science and technology community and the test and evaluation community. Add to these unique test requirements the desire of NASA to perform all new missions in a "faster, better, cheaper" mode, the partnering of all concerned parties became all the more important.

The Challenges and the Problems

In order to meet the challenges of these new and unique test requirements, there were many opportunities for test personnel to become involved with the project scientists in the early stages of program development. This collaboration proved to be very beneficial to all concerned parties as the test

requirements could be developed and test facilities modified as the project evolved. Because of the emphasis on doing things in a more cost-effective manner, it was decided early on to utilize existing facilities to the greatest extent possible in order to save schedule, time, and money.

In the case of simulating a Martian surface environment, it was determined that testing should be done in existing vacuum chambers because it would be cost prohibitive to build new chambers of various sizes to support the total test program. The major challenge was the fact that thermal vacuum and space simulation chambers are designed to provide a deep space environment of high vacuum (1×10^{-6} Torr) and -185°C temperatures. However, the Martian surface pressure is approximately 7 Torr, with CO_2 as the major gas component, and a surface temperature that varies from -40°C to -130°C depending on the time of day. At these conditions of pressure and temperature, the stainless steel vacuum vessel walls become very cold due to gas conduction between the chamber cryogenic shroud and the vessel. When the mild steel structural members of the vacuum vessel cool below -40°C they become brittle. Also, when the vessel becomes cold, condensation forms on the exterior of the vacuum vessel and moisture can penetrate electrical connectors and cables. Another problem appears when using the standard technique in thermal vacuum testing of using a liquid nitrogen flooded "scavenger plate" or "cold finger" to trap contamination and water vapor in the vacuum chamber. It was discovered that CO_2 at 7 Torr solidifies at approximately -120°C and the chamber could not be maintained at 7 Torr because a block of frozen CO_2 would form.

Contamination of optical surfaces and space flight components in environmental test programs presented many challenges during the testing of the Wide Field Planetary Camera and other Hubble Space Telescope instruments. It became necessary to devise methods of baking spacecraft components in vacuum chambers in order to ensure that contamination would not be deposited on optical surfaces once the instrument was on-orbit, and test methods needed to be changed to provide a contamination free test program. Some specific test requirements included: (1) the test hardware must not be re-contaminated at anytime during a bakeout or post test chamber shut-down, (2) the background emission rate of the chamber must be significantly below that of the test hardware i.e. the

chamber must initially be very clean, and (3) the contamination measurements must accurately verify that hardware cleanliness specifications have been met. Meeting contamination control requirements again necessitated close cooperation between the test and scientific communities.

During the space simulation test program of the Deep Space 1 (DS-1) spacecraft in 1998 (See Figure 2) the project scientists were concerned about the effects of the ion thruster engine on other spacecraft systems and the fact that the thruster had never been operated at the system level. The ion propulsion system had undergone extensive testing in a specially designed vacuum chamber, but had never been operated as a system with the spacecraft and flight software. The major concern of the space simulation operations personnel was the effect of the stream of ionized xenon gas coming from the engine, as it could erode the surface of the chamber cryogenic shroud and contaminate the optical components of the solar simulation system. Here again, a partnering relationship was required to study the effects of the ion thruster on the test facility (Hagood 1998). The final case presented similar problems to those encountered during the simulation of the Mars surface environment. In late 1998 the Environmental Test Laboratory at JPL was requested to assist in the



Figure 2: Deep Space 1 Spacecraft in the JPL 25-ft Space Simulation Chamber

testing of a high altitude, manned balloon gondola. The primary mission goal was to be the first manned flight around the world and to set a manned ballooning altitude record. The gondola was designed to fly at elevations up to 130,000 ft where temperatures can go as low as -135°C . Since the designers had only limited experience in the design of hardware for such a mission, an accurate simulation of the flight environment was essential. The goals of the tests were to obtain information regarding the thermal characteristics of the gondola and validate thermal models and predictions. A secondary goal was to provide information pertaining to arcing susceptibility of the electrical systems at predicted flight pressures.

Partnering to Develop Solutions

In the early days of the Mars Pathfinder project the problem of using CO_2 gas in vacuum chambers presented problems as previously discussed. Working with project scientists it was determined that for some test cases nitrogen gas was a suitable replacement for CO_2 . The thermal properties of nitrogen were sufficiently close to the Martian gas composition to provide a fairly accurate simulation; therefore, nitrogen was used to maintain the 7 Torr pressure in the vacuum chambers for most of the test programs. An experimental wind machine (See Figure 3) was used in several tests in an attempt to simulate Martian winds. This machine was developed through collaboration between the environmental test facility

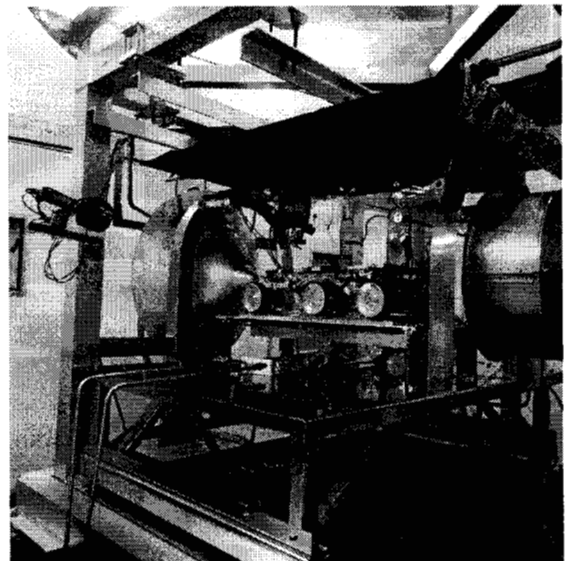


Figure 3: The Mars Pathfinder Rover and Wind Machine in the JPL 10-ft Space Simulator

personnel and the project science personnel; however, because of a lack of time and budget these tests were only partially successful, due to problems with the motor used to drive the fan that created the winds (Johnson et al 1995). However, sufficient data was collected to verify the scientist's computer models and to confirm that the thermal design would be effective for maintaining critical components within tolerance.

To meet the requirements of operating the Mars rover during system level solar-thermal-vacuum testing (See Figure 4), a special floor for the 25-ft Space Simulator was designed through a joint effort of the facility personnel and the project scientists (Johnson 1996).

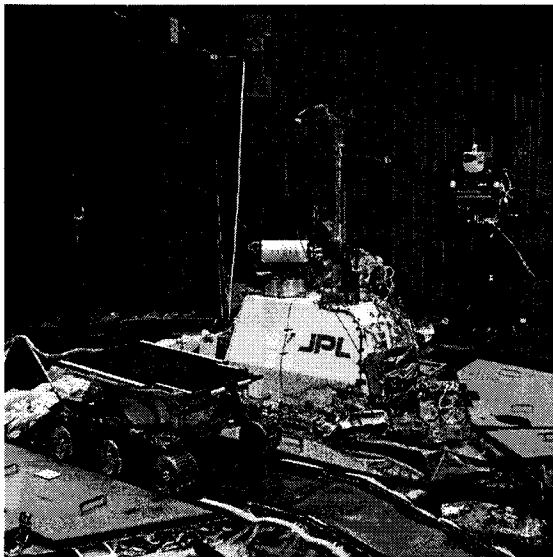


Figure 4: The Mars Pathfinder Spacecraft and the Mars Rover "Sojourner" in the JPL 25-ft Space Simulator

Potentially, the most serious problem encountered during the Mars Pathfinder test program was that of the structural members of the thermal vacuum chambers becoming so cold that the mild steel could fracture. To counter this problem, several practical solutions were developed by the facilities personnel, again working in conjunction with the project science community. The first step was to instrument the vacuum vessel walls and mild steel structural members with thermocouples to alert the chamber operators when the temperatures approached -40°C . With this warning in place, steps could be undertaken to initiate a chamber warm-up if required. Second, the operations crew conducted hourly walk-around

inspection tours of the facility and used hand-held non-contact temperature indicators to check areas that appeared to be getting too cold. Electrical heaters were used in the area of the chamber electrical penetration ports to eliminate condensation in the areas of cables and connectors. Last, fans were used to circulate air in the areas where condensation appeared on external surfaces of the chamber. All of these steps proved to be very successful and, although vacuum vessel external temperatures approached -40°C on several occasions, the testing programs were completed without interruptions.

During the test program for the Re/Max balloon gondola (See Figure 5), many of the same techniques developed for the Mars programs were implemented to protect the facilities.

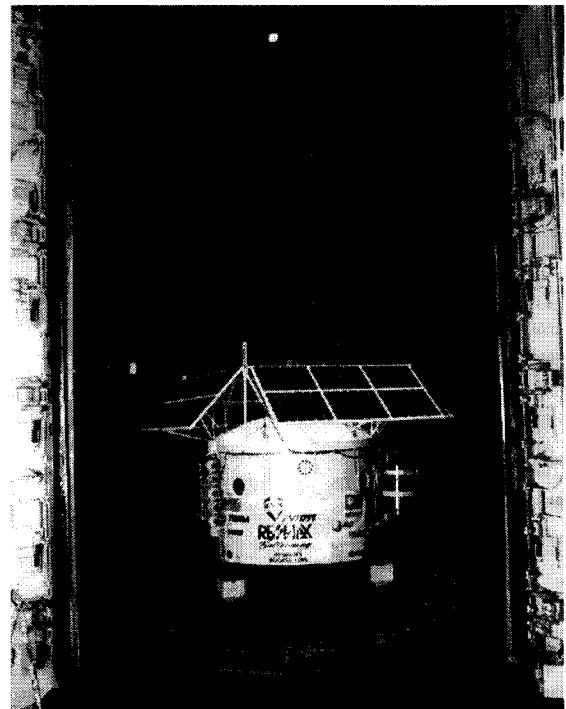


Figure 5: High Altitude Balloon Gondola in the JPL 25-ft Space Simulator

In addition, a different type of partnering arrangement was developed. In this case the designers and developers of the balloon flight project had little or no experience in building equipment designed to fly at the edge of space, so they approached experienced personnel at Lockheed Martin in Denver for assistance. The partnership of the design and test team in Denver and the facilities test team at JPL provided the ballooning team with the expertise needed to

successfully complete their design, fabrication, and test project.

To protect the vacuum chamber shrouds during the DS-1 ion thruster firing tests in the 25-ft Space Simulator (See Figure 6), a special target was fabricated from pure graphite foil and secured to an aluminum frame in front of the chamber cryogenic shroud. To protect the 23-ft diameter collimating mirror from any potential contamination in the chamber, a special cover was fabricated from carbon impregnated Kapton thermal blanket material. This cover was designed by the researchers in the thermal blanket and radiation shield shop at JPL, using their

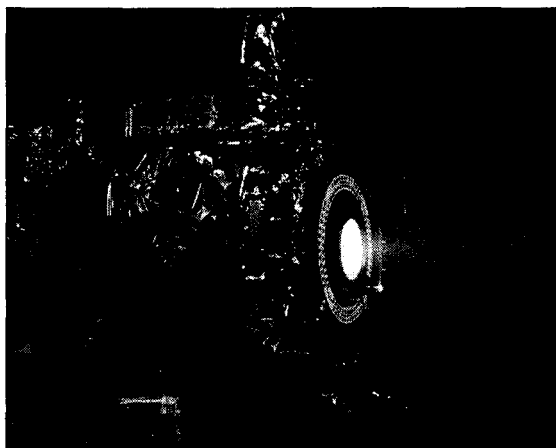


Figure 6: Deep Space-1 Ion Thruster Firing in the JPL 25-ft Space Simulator

years of experience in designing and fabricating thermal blankets and radiation shields for spacecraft.

During the fabrication and test programs for the Hubble Space Telescope, many new innovations were required in the world of test and evaluation due to the contamination control requirements developed by the project scientists. The techniques employed ranged from very simple to very complex. One simple solution was involved in preventing contamination of optical surfaces during vibration testing. Even when located in a Class 10,000 clean room there are enough oil vapors present in the vicinity of the shake table to contaminate sensitive optical components. The method to prevent contamination involved wrapping the test article in clean static dissipative material and introducing a purge of high purity nitrogen gas. This approach provided a simple, cost effective solution to the problem. In the case of verifying cleanliness

specifications in the vacuum chamber, special instrumentation was used to monitor the outgasing rates of both the chamber and the test article. Residual Gas Analyzers (RGAs) and Quartz Crystal Microbalances (QCMs) were used to measure high level and low level contamination levels during vacuum bake out testing (Johnson et al 1992). Data from these instruments were analyzed by project contamination control scientists to determine when the proper levels of cleanliness had been obtained. Since the project scientists were required to make the final determination of the effectiveness of the bakeout, it was imperative to establish a very close working relationship between the scientists and the test lab personnel.

In order to meet all of the contamination control requirements during the Wide Field Planetary Camera 2 (WF/PC II) project, JPL personnel determined that conventional vacuum chambers could not be used to obtain the desired bakeout results and at the same time meet the very stringent project requirements. Again, working closely with project research and science personnel a new chamber design concept evolved to effectively bake out hardware to levels required by the project. This new design used a test article containment system that is placed inside of the vacuum chamber shroud to prevent re-contamination of the test hardware. By enclosing the hardware in a stainless steel enclave (See Figure 7), and by always maintaining the

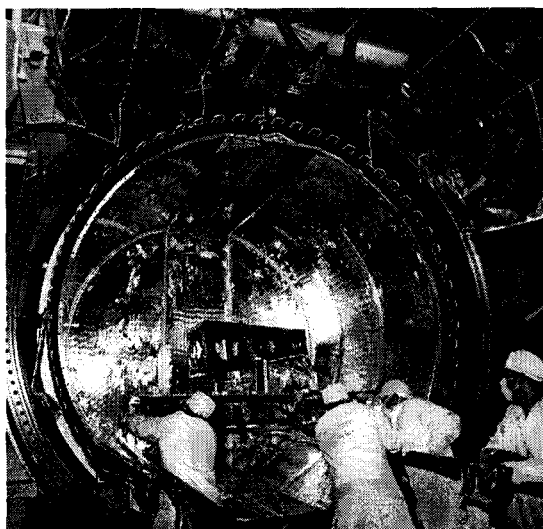


Figure 7: Wide Field/Planetary Camera II Optical Bench in the JPL 10-ft Thermal Vacuum Chamber with Enclave

enclave temperature above that of the shroud, the outgassed contaminants are prevented from condensing on the test hardware. Contaminants exit the enclave through orifices in the enclave and are removed from the chamber by either the vacuum pumping system or by condensing on the cryogenic shroud. During return to ambient conditions, the time when contamination is most likely to be re-condensed on the test hardware, the shroud is slowly warmed, then the enclave is slowly cooled and a purge of high purity nitrogen gas is introduced into the enclave. The combination of the purge and the slow warm up of the shroud minimizes the back flow of contamination into the enclave.

Conclusions

It has been shown in almost every case that when new and unique test requirements are levied upon the test community, cooperation and partnering among all the concerned parties is an essential element in the success of the test program. One of the most important aspects of the partnering arrangement is the involvement of the test engineers with the scientific community in the early stages of program development. This involvement aids in the test planning process and provides the test community with additional resources to help overcome some of the problems that are inevitably encountered.

Future partnering challenges will include continuing to work closely with the science community to develop new test methods and techniques for new test requirements and to increase the number of partnering arrangements with industry, academia, and other governmental agencies to effectively utilize environmental testing facilities.

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